EXHIBIT 1

A New Thick-Film Technology for mm-Wave MCM and Microwave Devices

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ABSTRACT

The application of a new, advanced thick-film technology for the fabrication of MCM or microwave devices operating at mm-wave frequencies is described in this paper. Data are presented over the frequency range 45MHz-40GHz which show that the technology can be used to realise MCM or microwave interconnections with outstanding performance compared to existing thick-film materials.

Key words: Microwave, MCM, Thick Film

Introduction

The rapid expansion in commercial microwave systems, particularly for mobile radio systems, has created a demand for low-cost, high performance microwave circuit materials and processes. The circuits needed may be straightforward planar microwave circuits, usually in a microstrip format, or MCM devices. However, in both cases the material requirements are essentially the same. The key geometric requirements are for smooth surface finish, for both the conductors and the dielectrics, and for well defined conductor track edges and high track resolution.

It is primarily skin depth effects which dictate the requirements for surface finish. The skin depth (δ) for a conductor is given by the standard expression

$$\delta = (\pi f \mu_o \sigma)^{-0.5}$$

where f is the frequency, μ_o is the permeability of free space and σ the conductivity of the conductor. Thus, for a gold conductor at 30GHz, we have δ=0.37μm. This provides an indication of the degree of roughness that can be tolerated, both on the surface and edges of a conductor, if line losses are to be kept to an acceptable value.

Traditionally, it has been difficult to achieve the required conductor quality with thick-film technology. In this paper the results of physical and microwave measurements are described, which

show the potential of a new material technology for realising microwave circuits at mm-wave frequencies.

Photo Patterned Thick Film Technology

The use of a thick film technology would be attractive due to its basic low cost processing, but a way has to be found of improving it's performance significantly. This paper describes the performance of such a technology - KQ - which uses advanced thick film materials in combination with photoprocessing and ceramic substrates to solve many microwave circuit problems.

The KQ materials system consists of thick film gold conductors and dielectrics. These materials have been described in detail elsewhere [1]. Novel particle sizing in the gold conductor allows the printing and firing of a very smooth gold conductor of high density which in turn allows the application of a photoresist and the patterning of the conductor by a simple etching process. The accuracy of conductor achievable is shown by the pair of 50 micron coupled lines on 96% alumina in Figure 1. The dielectric materials use a borosilicate glass based technology which provides low dielectric constant (3.9) and loss (10^{-4}). The incorporation of a photosensitive vehicle into the dielectric allows the definition of precise via geometry's, as small as 50 micron.

A summary of the low frequency KQ material performance is given in Table 1. It can be seen that the high conductivity of the gold material combined with the low K and loss of the dielectric material together with their excellent geometrical resolution provides a suitable basis for a thick film material for use at a microwave frequencies.

Table 1 - Summary of KQ Properties

Conductor	Gold Thick Film
Conductivity	2.6 Milliohm per Square
Line resolution	< 20 Micron
Backlight density	100%
Surface roughness	0.4 micron Ra
Edge acuity	1 Micron
Dielectric	Silica Borosilicate
Via resolution	< 50 Micron
Dielectric constant	3.9
Loss tangent	< 10^{-4}

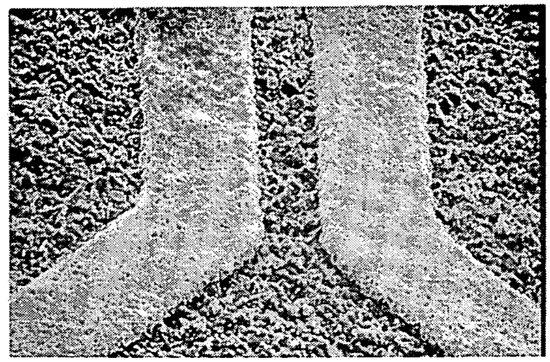

Figure 1 - 50 Micron Coupled Lines

Physical properties

The geometric properties of a number of test lines fabricated using the new KQ process were investigated using a surface profiler. The line dimensions were chosen to be consistent with those found in high frequency MCM and microwave devices. Shown in figure 2 is the

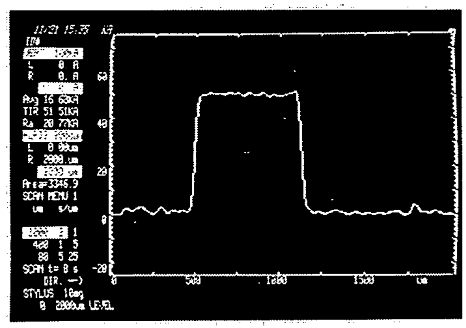

Figure 2 Profile of a 650μm wide KQ gold track on 99.6% alumina.

profile of a 650μm microstrip line fabricated on a 99.6% lapped alumina substrate using KQ gold conductor. The profile shows well-defined line edges, which are necessary both to reduce losses and to facilitate the construction of coupled line devices such as filters and directional couplers. Also evident is the low surface roughness. In this case the rms surface roughness was 0.09μm. A second profile, this time of a narrow 50Ω track fabricated using KQ gold on a printed KQ dielectric is shown in figure 3. This demonstrates that the technology is capable of providing fine line geometry, whilst maintaining a good surface

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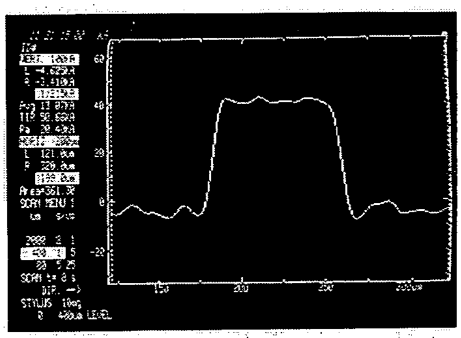

Figure 3 Profile of a 78µm wide gold track on KQ dielectric.

profile and low surface roughness, ⟨1µm. These are significant factors, both for microstrip circuits and for high density MCM devices.

Microwave performance

In order to establish the microwave performance of the material, a 50Ω microstrip line was fabricated using KQ materials. The test structure is shown schematically in figure 4. It consisted of an alumina

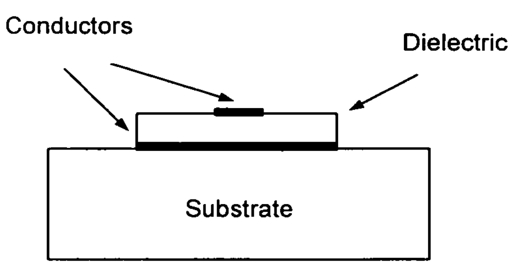

Figure 4 Cross section of test structure

substrate, used purely to give rigidity, with printed layers of conductor and dielectric to form the RF transmission line. The gold ground plane was printed directly on the alumina and on top of this was the printed dielectric, and finally a signal track as the top layer. Thus the microwave transmission line has very small dimensions, a significant factor for the future development of compact mm-wave circuits. The printed dielectric, which had a relative permittivity of 3.9, was 40µm thick and the track width 86µm, giving the line the desired characteristic impedance of 50Ω. The characteristics of the line were measured using an HP8510 Vector Network Analyzer, with the test circuit mounted in a Wiltron MIC test jig. It should be noted that the test edges and underside of the alumina supporting substrate were also coated with gold so that the Wiltron jig made positive contact with the intermediate microstrip ground plane. Data for the measured line loss are given in figure 5. Appropriate compensations

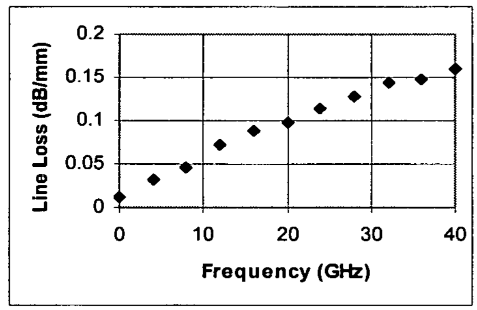

Figure 5 Variation of line loss with frequency

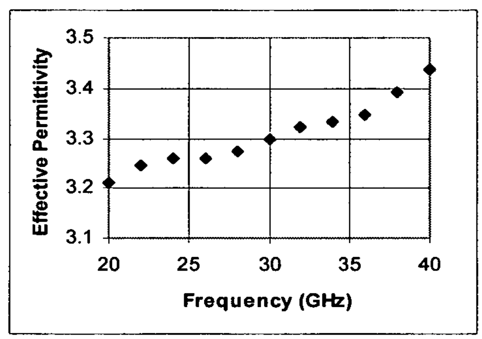

Figure 6 Variation of effective relative permittivity with frequency

were made for the mismatch loss introduced due to the physical mismatch between the tab of the test jig and the narrow 50Ω microstrip line. A quasi-linear variation of line loss with frequency is observed, with no significant or sudden degradation in performance as the mm-wave band is approached. The performance compares vary favourably with that obtained using other, more expensive fabrication technologies and is significantly better than the previously reported losses in thick film circuits at these frequencies.

Further measurements were made on the phase response of the test structure over the frequency

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range 20-40GHz to establish the potential of the technology for fabricating distributed microwave circuits at near-millimetre wave frequencies. From measurements of the transmission phase change through the structure, the effective relative permittivity of the structure, as a function of frequency, was extracted. The results are shown in figure 6. These results show that the line exhibits low, quasi-linear dispersion, over the frequency range examined. Using these results the absolute value of relative permittivity was calculated from the expressions given by Kirschning and Jansen [1]. These expressions are reported to offer the most accurate representation of dispersion effects at millimetre-wave frequencies. The results show that the relative permittivity is within 5% of the value previously measured by Huang et al, [2] using a more rigorous, resonant cavity technique.

Conclusions

Measurement data, both electrical and physical, have been obtained which show that this new thick-film technology offers outstanding potential for the development of microwave and MCM circuits up to at least 40GHz. Although the upper frequency limit of the present measurements was 40GHz, there is nothing in the trend of the results to show that there will be a significant deterioration in performance at higher mm-wave frequencies. Further work on the fabrication of microwave filters has shown good agreement between simulated and measured data. It is clear that the new material and process technology combines low-cost fabrication with excellent microwave performance for integrated devices operating into the mm-wave band.

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